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Summary of Isotopic Age Determinations in Pennsylvania

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PREFACE

For more than three decades, individual research workers have been publishing the results of radiometric age determinations of Pennsylvania rocks and minerals. This report is a summary of this information up to 1969. Also included are 12 unpublished dates determined for the Pennsylvania Geological Survey by Isotopes, Inc. Although these age data primarily give the time at which a thermal and/or local geologic event occurred, they may have broader regional significance. When considered together, these data yield pertinent information concerning the chronology of metamorphism, magma intrusion, and, in some cases, of rock deformation. Because, in a general way, such processes are part of major crustal deformations (orogenies), they too can be dated, at least in part. Knowledge gained from isotopic age determinations in Pennsylvania aids in unravelling structural history, in solving problems of stratigraphic correlation, and in the understanding of the formation of many kinds of Pennsylvania's metallic and non-metallic deposits.

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SUMMARY OF ISOTOPIC AGE DETERMINATION IN PENNSYLVANIA

by
D. M. Lapham and S. I. Root

ABSTRACT

Isotopic ages of Pennsylvania rocks and minerals are summarized for the following provinces: Piedmont, Blue Ridge, Reading Prong, Valley and Ridge, Appalachian Plateaus, and Triassic Lowlands. Included are the unpublished isotopic ages of 12 samples. Selected age determinations from neighboring states are included. Ages range from about 1190 to about 190my and fall into the following major approximate-age groups: 1050 to 1150my (the so-called "Grenville" Precambrian metamorphism), 820 to 910my (volcanism in the Blue Ridge; plutonism and metamorphism in the Reading Prong), ill-defined thermal event(s) between 460 and 600my (termed proto-Taconic), 425 to 460my (Piedmont plutonism, metamorphism, and probably penecontemporaneous Taconic deformation), 320 to 380my (Acadian thermal events), possibly younger thermal and/or deformational events between 220 and 300my, and a Triassic magmatism about 190 to 200my ago. A review of these major age groups relates thermal events to possible specific geologic events in each province and notes the unsolved problems, particularly the differences in recorded radiometric events among the geologic provinces.

TECHNIQUES OF RADIOMETRIC ANALYSIS

Since early in the twentieth century, various techniques have been used to determine the age of rocks by chemical and radiometric techniques. With the advent of mass spectrometric techniques for analyzing small quantities of an element, it has been possible to date isotopically many minerals and to establish a radiometric age sequence of geologic events.

Uranium-lead (U^{235}/Pb^{207} and U^{238}/Pb^{206}) and lead isotopic analyses ($Pb^{207/206}$) from U^{235} and U^{238} decay allow dating of uranium-bearing minerals in rocks. The most commonly used mineral is zircon. The lead-alpha (Pb-α) radiometric method of age determination is based upon radiogenic lead content and the alpha count for zircon and is primarily a preliminary or reconnaissance tool. The potassium/argon (K^{40}/Ar^{40}) isotopic system is used to date potassium-bearing minerals such as biotite, muscovite, phlogopite, orthoclase, sanidine, hornblende, and glauconite. The isotopic ratio of rubidium to strontium based on the decay of radioactive Rb^{87} to Sr^{87} permits dating of biotite, muscovite, microcline, and

lepidolite. A less common and less reliable technique, which has been used to date magnetite in Pennsylvania, is the measurement of the formation of the helium isotope produced by decay from Th^{232} or U^{235} and U^{238}. In addition to isotopic analysis of a discrete mineral, the K/Ar and Rb/Sr techniques frequently are utilized to determine the age of whole-rock samples. A recent development uses the fission track dating method based upon a direct relationship between the number of fossil fission tracks in a mineral and the amount and age of the uranium in that mineral as determined by an induced fission track. Minerals used are apatite, mica, epidote, sphene, and zircon. Very little of this work has been done on Pennsylvania samples (Rasmussen, 1969).

Analyses of organic material less than about 70,000 years in age is accomplished by the radiocarbon system of age determination (C^{14}). Age measurements by this technique commonly are used for problems involving Pleistocene or recent organic material both for geological and archeological problems. Consideration of age determinations by C^{14} is not within the scope of this paper. Results of C^{14} determinations are published annually by the *American Journal of Science* in a radiocarbon supplement volume.

Age dates are generally published with a stated error range, either in my (millions of years) or in percent. Such an error range almost invariably refers to an analytical-error estimation resulting from such problems as uncertainty in a decay constant or a known range in the analytical accuracy of an isotope. The latter is particularly important at low isotopic concentrations. Error range generally does not refer to errors that may arise from complicating factors such as mineral alteration and other sample inhomogeneities or mixed age assemblages; hence, an error range does not necessarily provide the age limits of a thermal event that can be directly applied to the age of some geologic event (compare columns 4. and 5., Table 2). In most published reports, error in isotope analysis is reported to be about $\pm 2\%$. In addition to this analytical error, procedural errors generally result in a total of about $\pm 5\%$ of the stated age (Table 2) except where there may have been significant sample inhomogeneity. In most cases, errors of reproducibility are determined by duplication of analyses. As a consequence of these kinds of errors, reported ages are referred to as "apparent" ages (column 4., Table 2) rather than "real" or "true" ages.

For detailed discussion of the theories and techniques of isotopic dating and interpretation, the reader may consult such references as Rankama, 1954; Faul, 1954; Hamilton, 1965; and the references at the end of this report. A glossary of terms is also included at the end of this report. The relation of mineral age dates to various geologic events in

the northeastern United States is summarized by Rodgers (1967) and Lyons and Faul (1968).

By judicious selection of isotopic analytical techniques and with a sufficient number of radiometric analyses, it may be possible to distinguish between the age of an original mineral or rock and subsequent metamorphic or orogenic events. During the past decade a significant number of radiometric age data on Pennsylvania samples has been published. The igneous rocks investigated range in age from metamorphosed Precambrian plutons (older than 600 million years) to Triassic diabase and associated ore (see time scale, Table 1). There is no radiometric evidence for ages that can be assigned to any deformational episode younger than the Alleghanian (240 to 290my). Sedimentary, igneous, and metamorphic rocks have been analysed. With the possible exception of the Piedmont crystalline belt, no area has received detailed study (Figure 1) and even in the Piedmont there is such geologic complexity that many problems remain unsolved. The purpose of this report is 1) to assemble the Pennsylvania isotopic age dates and those of adjacent areas which bear upon Pennsylvania geology (Table 2); 2) to summarize the geologic interpretations of these raw data; and 3) to note certain geologic problems in Pennsylvania that require additional elucidation by radiometric analyses.

TABLE 1. *Geologic Time Scale*

ERA	*PERIOD or EPOCH*	*AGE (in millions of years)*
Cenozoic	Pleistocene	less than 1
(Tertiary)	Pliocene	1-10
	Miocene	11-25
	Oligocene	26-40
	Eocene	41-60
	Paleocene	61-70
Mesozoic	Cretaceous	71-135
	Jurassic	136-180
	Triassic	181-225†
Paleozoic	Permian	226-270
	Carboniferous	271-350
	Devonian	351-400
	Silurian	401-425
	Ordovician	426-500
	Cambrian	501-570*
Precambrian		571* and older

* This limit is not firmly established (Fairbairn and others 1967).

† Armstrong and Besancon (1970) suggest an older range for the Triassic, from 210-255my.

GEOLOGICAL LIMITATIONS OF RADIOMETRIC DATING

Although in some instances an attempt has been made here to assess the limitations of the reported ages (columns 4, 5, and 9, Table 2), for more detailed discussions the original references should be consulted. In utilizing these age determinations, some of the major limitations that must be considered are:

1) The radiometric method used. For example, the Pb-α and He methods are particularly subject to error.

2) Fictitious ages that result from dating a mixed assemblage (i.e., an assemblage of minerals of more than one age) yielding an average rather than a true date, especially for whole-rock and zircon determinations.

3) Fictitious ages that result from partial re-equilibration resulting from a succession of thermal events such as secondary alteration, metamorphism, erosional unloading, and faulting. Fission tracks are particularly susceptible to low temperature modification by annealing and/or loss of uranium in some minerals such as mica (Fleischer and others, 1964).

4) Fictitious ages that result from the possible selective removal of decay products (Pb in the U-Pb system, argon in the K-Ar system, or Sr in the Rb-Sr system) by solution or diffusion processes.

5) The possible difference between the effect of thermal diffusion through a particular mineral lattice and a geologic event (e.g., metamorphism). For example, the identification of a particular regional metamorphic facies with the development of a specific penetrative rock fabric has not been definitely established in any of the major geologic provinces of Pennsylvania. Similarly, multiple age dates in any one region (Table 2, Piedmont Province) commonly indicate more than one thermal alteration, but all may have occurred within a single orogenic pulse (e.g., the Taconic orogeny). Probably in most instances the lack of a radiometric date for an established geologic event (e.g., Taconic, Acadian, etc.) in any given area is the result of a lack of data rather than the absence of that event. Alternatively, the geologic event may not have been of sufficient thermal magnitude to initiate re-equilibration of the minerals in the rock units, or an older age may have been obliterated by subsequent re-equilibration.

Despite the problems inherent in many isotopic age interpretations, radiometric data are invaluable for the solution of many geologic problems. Among some of the problems to which this summary is relevant are the assigning of rock units to a chronological sequence within the geologic time scale (Table 1); the determination of the original age of such problematical units as the Glenarm Series of the Piedmont and of unfossiliferous rock units; to aid in the correlation of deformational and

metamorphic chronologies, particularly with regard to such major events as Precambrian ("Grenville") metamorphism, Blue Ridge volcanism, and Taconic, Acadian, and Alleghanian orogenies; to identify unloading erosional events with reference to regional warping and sediment provenance after the attainment of a stable thermal and/or chemical exchange environment; to delineate any possible outward migration with time, of a deformation from the core of eugeosynclinal belts (Lapham and Bassett, 1964); and to assist in determining the extent of basement involvement in deformation.

The summary presented in the succeeding section is an initial attempt to focus attention upon these problems. The geochronological data are summarized by province in order of decreasing age in Table 2, and the sample locations are illustrated in Figure 1.

ISOTOPIC AGE DETERMINATIONS

THE PIEDMONT PROVINCE

For purposes of discussion here, the Piedmont Province includes all units south and east of the Triassic basin, including the Lancaster Valley (Figure 1).

Samples dated in the Pennsylvania Piedmont range in apparent age from 1120my to as young as 216my (see Remarks, item 26, Table 2). Major concentrations of dates fall into three groups: 1050 to 1120my, about 425 to 460my, and about 320 to 360my. In addition, there are three Pb-α dates between 785 and 910my which might correlate with a similar age group in the Blue Ridge Province, but which probably belong to the older 1050 to 1120my group because Pb-α dates commonly are too young and because some of the zircons dated probably are older detrital grains. There also are several Piedmont dates younger than 320my (items 22 to 26, Table 2, and unpublished fission track dates by Rasmussen, 1969), which may correlate with a lead loss in the Blue Ridge Province at 240my, but there is no evidence for a geologic event in the Piedmont at this time. Granitic plutonism at this time (about 240my ago) has been radiometrically documented in New England (see summary by Lyons and Faul, 1968) and a thermal event that is neither metamorphic nor tectonic has been recorded in the south-central Appalachians (Long and others, 1959). At least some apparent ages that have been reported between these major groups of Piedmont dates probably are fictitious in terms of discernible geologic events (column 5, Table 2), commonly representing the effects of thermal diffusion or mixed ages.

The Precambrian dates in the Piedmont at about 1100my, commonly referred to as an age equivalent of events in the Grenville Province, may require interpretive revision. This age group is based upon dates from

euhedral zircons in igneous and metamorphic units in Pennsylvania (Table 2, item 1.). Recent work raises the possibility that this group of dates represents a second generation event in the type Grenville Province area (Krogh and Davis, 1969) and therefore this age group in Pennsylvania should not be referred to as of Grenville age.

Another possible geologic event, here termed proto-Taconic, is tentatively suggested to have occurred over some unknown time between 460 and 600my (items 7, 8, 9 (?), 10 (?), 11 (columns 5 and 9), 59-62, 82, Table 2). As yet, the nature of this event in terms of volcanism, plutonism, or metamorphism cannot be defined although the former two seem likely at the present state of our knowledge. This ill-defined event is possibly equivalent to either the Avalonian or Penobscot events in New England (Rodgers, 1967) or the Neponset of Fairbairn and others (1967). Radiometric dates from quartz diorites (510 to 565my) in Maryland (Steiger and Hopson, 1964; Wetherill and others, 1966) may be correlative with similar, less well-documented events in Pennsylvania. Hopson (1964) believed some of the mafics, which are instrusive into the Glenarm metasediments, to be older than 510-565my. However, Higgins (written communication) believes them to be younger than Hopson concluded, thus reducing the maximum age of both the plutons and the metasediments of the Glenarm Series. Higgins also believes that some of these granitic plutons are gradational with Glenarm pelitic schists and may approximate the age of the Glenarm Series. The ultramafic plutons of southern Lancaster and Chester counties are believed to belong to this period of lower Paleozoic activity (Remarks, item 11, Table 2) and perhaps are correlative with the earliest regional metamorphism of the Glenarm Series (Lapham, unpublished data). Certainly the deposition of the *oldest* Glenarm Series sediments in Pennsylvania cannot have occurred less than about 460my ago (item 11, Table 2) and probably is somewhat older (mafic and ultramafic rocks in Pennsylvania intrude the lower pelitic schist and boulder gneiss of the Glenarm Series as defined by Southwick and Fisher, 1967, in Maryland). Such an age agrees well with K/Ar minimum dates for serpentinite from Quebec of 479 to 495my (see summary by Lyons and Faul, 1969, p. 308).

Geologic events are represented by age dates of the next age group, 425 to 460my. In some cases, they are not clearly separable from the 460 to 600my thermal events in Pennsylvania because continuous reequilibration to 425my of the rocks representing older events is believed to have occurred in some samples. In Maryland, Hopson (1964) proposed a succession of magmatic events from mafic to granitic, a sequence that is currently under revision by Higgins (written communication). Because the events that occurred between 425 and 460my ago, such as

pegmatite intrusion (Wetherill and others, 1966), regional metamorphism, and probably mafic intrusion (Lapham and Bassett, 1964) may be causally related to the older group, both may be genetically associated with the Taconic orogeny; hence, the use of proto-Taconic (between 460 and 600my) and Taconic (425 to 460my) in this discussion.

The youngest, well-established group of dates, 320 to 350my, is represented by the largest number of age determinations in the Pennsylvania Piedmont as well as elsewhere in Pennsylvania and in the Appalachian Mountain System (summarized by Hadley, 1964). However, it is not clear what geological or thermal event this age group represents. Some pegmatite intrusion may be attributable to this Acadian age, but the possibility of re-equilibration of an older pegmatite cannot be excluded. If regional metamorphism or erosional unloading (see Hadley, 1964) caused pegmatitic micas to re-equilibrate, then there are no substantiated magmatic events established in this age group. Many of the dates between 350 and 420my are believed to be fictitious (Lapham and Bassett, 1964), resulting from 420 to 460my inherited micas yielding mixed dates, or from only partial re-equilibration with the younger event (column 5, items 13 to 16, Table 2). The fission track mica and apatite age determinations from an Embreeville pegmatite (not presented in Table 2 because of uncertainties in interpretation), range in age from 200 to 340my and average about 280my (Rasmussen, 1969). They are believed to belong to a 300 $\pm$ 35my age group (op. cit.). They also indicate that there has not been a significant thermal metamorphic event here in the Piedmont that exceeded about 145°C. (Fleischer and others, 1964) since about 280my ago.

Although a late Paleozoic Alleghanian event has not been clearly established in the Pennsylvania Piedmont from radiometric data, some apparent ages (e.g., item 75, Table 2), may be an indication that thermal loss did occur in this area at the close of the Paleozoic. Retention of radiogenic argon by Piedmont micas yielding ages of 320my or more indicates that erosional stripping in some areas of the Piedmont had begun well before the close of the Paleozoic; i.e., previous to 280my, even though locally the depth of burial was still sufficient to permit a continued loss of argon through late Paleozoic time. There is abundant geologic evidence for this stripping reflected by the accumulation of a Devonian Catskill clastic wedge.

Correlation of major thermal events in the Piedmont with the successive deformations proposed by Freedman and others (1964) is uncertain. From a review of mica alteration and structural orientation, Lapham and Bassett (1964) suggested that the earliest deformation (D_1) may coincide with a regional metamorphism correlative with the 425 to

460my age group, and the second deformation (D_2) with the 320 to 350my age group. However, it is also possible that D_1 and D_2 are older, 460 to 600my and 425 to 460my, respectively, or that both belong to only one of these age groups. It should also be noted that D_2 in the Pennsylvania Piedmont was essentially a basement-doming deformation (Freedman and others, 1964). Wetherill and others (1966) proposed that the final growth of the gneiss domes in Maryland occurred between 425 and 460my ago. Whether or not vertical basement tectonics occurred at the same time in the Pennsylvania and Maryland Piedmont remains to be established.

THE BLUE RIDGE PROVINCE

Only a small part of the Blue Ridge Province is present in Pennsylvania (at South Mountain, along the southwest margin of the Triassic Gettysburg basin). The U/Pb and Pb/Pb dates of Rankin and others (1969) are the only available published data on this province. Their studies indicate that zircon crystallized in rhyolite at about 820my with a subsequent episodic lead loss at about 240my. This volcanism apparently is widespread throughout the Blue Ridge of the central and southern Appalachians (op. cit.). In Pennsylvania, the only other well-defined events (plutonic and metamorphic) at this time occurred in the Reading Prong (items 30, 70-74 and 78-81, Table 2). Pennsylvania Piedmont Pb-α dates, which are unreliable, and a West Virginia Rb/Sr basement gneiss date (item 68, Table 2) may belong to this 820-910my age group.

Two interpretations can be considered for the Blue Ridge whole-rock metarhyolite dates at 324 and 306my (items 29 and 30, Table 2): 1) that they represent an actual thermal event, and 2) that they are fictitious ages representing the resultant of mixed mineral ages or of partially re-equilibrated minerals. A large cluster of dates in this range from Piedmont samples to the east and a few from Valley and Ridge samples to the northeast and northwest (Figure 1.) may be a good indication that these dates represent an Acadian event. On the other hand, the presence of younger dates (items 27 (Remarks), 29, 31 and 32, Table 2) raises the possibility of partial re-equilibration by a younger, Alleghanian event. In this case, the 324 and 306my Blue Ridge dates would then be only in fortuitous agreement with this age group elsewhere and would not represent an actual thermal event.

Age dates in the Blue Ridge Province now clearly indicate a late Paleozoic Alleghanian event; indeed, the dates from this province are the only radiogenic indicators of an Alleghanian event in Pennsylvania (items 27 (Remarks), 31, and 32). These dates are compatible with a late Paleozoic age of major movement of the Blue Ridge thrust sheet,

with late Paleozoic deformation in the Valley and Ridge that involved Pennsylvanian sediments in the anthracite region, and perhaps with the folding of the Dunkard Group of Permian sediments. A "basement" gneiss date of about 235my in New Jersey (item 75, Table 2) could be an indication of basement metamorphism during the time of Blue Ridge thrusting; however, the gneiss may be of Paleozoic age rather than an equivalent of the Baltimore Gneiss (Southwick, 1964).

THE READING PRONG PROVINCE

The Reading Prong province of east-central Pennsylvania is a subdivision of the New England (Precambrian) Province.

Apparent age dates (K/Ar and Pb-α) from the Reading Prong in Pennsylvania are sparse (items 33-38, Table 2). However, additional data from New Jersey and New York (items 70-74 and 78-81, Table 2; Long and Kulp, 1962) indicate that the grouping of dates between 800 and 900my reflects a real thermal event in Pennsylvania, presumably a metamorphic recrystallization of 1150my granites and emplacement of microperthite granites (Drake, 1969, p. 74). The original metamorphism is believed to correlate with an 1100my age group (Long and Kulp, 1962) but has been modified by more than one period of thermal argon degassing (items 36-38, Table 2.). Events substantially younger than about 800my have not been well established in samples from the Reading Prong, although some Paleozoic thermal diffusion is now evident (items 37 and 38, Table 2). Mica and whole rock determinations yield widely divergent ages. This is particularly interesting because two of the Pennsylvania ages in the 800-900my group (items 34 and 35, Table 2) and two New York-New Jersey analyses (items 74 and 81, Table 2) were K/Ar determinations on mica. These particular micas, in which re-equilibration (cessation of argon degassing) is believed to occur at less than 200°C, therefore have not been subjected to significant thermal re-equilibration during Paleozoic time. Both Pennsylvania samples occur in the westernmost Reading Prong (Little South Mountain) segment. Apparently here radiogenic dating might support the proposition of tectonic emplacement of the Reading Prong as a rootless brittle mass; i.e., the micas show no effects of a Paleozoic reequilibration. Furthermore, if this Reading Prong unit were a thrust remnant of the Piedmont to the south, either it was thrust previous to the Piedmont Paleozoic thermal re-equilibration or it was too shallow to be affected by a deeper Piedmont alteration. Reading Prong units east of here (items 37 and 38, Table 2), however, do show a younger apparent re-equilibration; hence, from the presently available limited data two separate tectonic and/or metamorphic areas in the Reading Prong may exist, if these whole-rock dates are reliable.

The other Reading Prong age determination in Pennsylvania (item 33, Table 2) is listed as a Pb-α analysis of a hydrothermal zircon from serpentinized marble near Easton, Pa. and is chronologically and genetically unrelated to the ultramafic intrusions of Lancaster and Chester counties.

The older group of Reading Prong dates correlates with the age of Blue Ridge volcanism (approx. 820my), although no extrusive activity is known in the Reading Prong. The younger Paleozoic dates in the Reading Prong correlate with Acadian and/or Alleghanian events elsewhere in Pennsylvania.

THE VALLEY AND RIDGE PROVINCE

Age determinations in the Valley and Ridge Province are scanty and have been restricted to whole rock analyses in the Hamilton Group and the Reedsville or Martinsburg formations (items 39-47, Table 2). The interpretation of these dates in terms of tectonic (dynamothermal metamorphism) or diagenetic chronology has been a subject of discussion in the literature (Whitney and Hurley, 1964; Pierce and Armstrong, 1966; Bofinger and Compston, 1967).

On the basis of the work by Pierce and Armstrong (1966), Armstrong (1970), and unpublished data (Pa. Geological Survey), it is tempting to correlate the two sets of dates (444-473my and 324-372my) with their age group counterparts (Taconic and Acadian respectively) in the Piedmont, Reading Prong, and Blue Ridge. However, the only apparently certain conclusion is that faulting has induced some radiogenic argon loss from an original age of at least 444 or 473my to an apparent age of about 372my and less (items 43 and 45, Table 2). If equilibrium were not established, the age of the faulting could be considerably younger (Alleghanian).

Evidence is presented by Bofinger and Compston (1967) that Rb/Sr ages on the Hamilton Group reflect diagenetic re-equilibration rather than the influence of older, inherited micas. Certainly an age of 348my (item 41, Table 2) does not directly reflect any known radiogenic, tectonic, or metamorphic event elsewhere in Pennsylvania. If diagenetic re-equilibration is the fundamental explanation for these sedimentary Rb/Sr whole-rock dates and if similar K/Ar diagenetic re-equilibration occurred, the 444my Reedsville or the 473my Martinsburg dates might reflect the time of deposition; however, such a spread in depositional age seems unlikely. They also are roughly consistent with a proto-Taconic age for minerals that may have been the sediment source. Some combination of the two explanations presently seems most likely.

An interesting aspect related to radiometric dating is the recognition on mapped evidence of different times of orogeny in the Valley and

Ridge Province. At the Delaware River, Drake and others (1960) and Epstein and Epstein (1970) have demonstrated profound Taconic deformation: the Ordovician Martinsburg Formation was folded and eroded prior to deposition of the Silurian Shawangunk Conglomerate. Maxwell (1962) dates the development of slaty cleavage in the Martinsburg Formation as pre-Silurian. To the south in the Cumberland Valley, Root (1970) reports continuous sedimentation across the Ordovician-Silurian boundary. Thus, the dates between 324 and 372my (items 43 and 45, Table 2) must be further substantiated before concluding that faulting here was an Acadian event. Most of the field relations indicate that the major orogeny was a terminal Paleozoic Alleghanian event for which no radiogenic record (other than partial re-equilibration effects) has yet been found in the Valley and Ridge.

Ages obtained from samples of basalt and diabase (140-375my) in the Bunker Hill volcanics (Urry, 1936, items 42, 44, 46, and 47) interbedded with the Martinsburg Formation, all of which may be allocthonous, are among the earliest of radiometric analyses. This technique is not considered reliable today.

THE TRIASSIC LOWLANDS PROVINCE

Radiometric age determinations on Pennsylvania Triassic units have been of two types: (U, Th)-He measurements on magnetite from diabase sheets, and (U, Th)-He and K/Ar dates from diabase and from magnetite ore zones associated with sheet diabase. Within the limits of error of the technique (Green and Damon, 1963), all measurements indicate an age of about 195my. The range of probably reliable dates, based on a 10 percent magnetite leach (Green and Damon, 1963), is 188 to 202my. No age difference between diabase and ore has been detected but, in any case, any such differences probably are too small to be measured by the presently available techniques. The extrusives, believed to be somewhat earlier than the intrusive diabase (Lapham and Gray, in press), have not been dated in Pennsylvania. An age determination by Erickson and Kulp (1961) on the Watchung basalts (79my) was assumed to be equivalent in age to the 195my old Palisades sill (item 76, Table 2). This assumption remains to be substantiated. Neither the older Triassic sediments nor the apparently younger diabase dikes (with one exception, Table 2: Note) have been dated radiometrically.

If burial metamorphism has reduced the apparent age of upper Triassic lithologies, the true age of the upper Triassic in eastern North America may be closer to 210-230my (Armstrong and Besancon, 1970) than the presently accepted minimal age of 180my for the Triassic-Jurassic boundary.

THE APPALACHIAN PLATEAUS PROVINCE

Generalizations cannot be drawn from the three locations studied radiometrically in this province (items 41 (Fayette County), 55, 56, and 57, Table 2; Figure 1).

Samples of Precambrian phyllite and schist from a core near Erie, Pennsylvania yielded a K/Ar age of 908my and Rb/Sr ages of 544 and 633my. The former correlates with dated samples of the Precambrian from other wells (Saylor, 1968); the latter, younger dates are of uncertain interpretation.

The peridotite dike dates (408 and 368my) are older than the units which they cut and thus do not represent the time of *in situ* magmatic crystallization. The samples contain altered inclusions of possibly older sedimentary lithologies that may explain the anomalous dates.

The Hamilton Group drill-hole sample from the Plateau (item 41, Table 2) has an age of 384my, roughly consistent with Hamilton Group samples from the Valley and Ridge Province, indicating that post-Devonian burial has not greatly affected the Rb/Sr apparent age.

DISCUSSION

The new isotopic dates presented here are of considerable significance because there was no prior record in the Blue Ridge of Pennsylvania of any 310-350my thermal event or in the Reading Prong of Pennsylvania of any 310-350my nor 240-290my thermal events. Except for lead loss in Blue Ridge zircons at about 240my, the youngest recorded radiometric ages (recrystallization) in these two provinces occurred about 820-840my ago (Table 2). With the new dates, there is some evidence for an Acadian event in both provinces and additional support for an Alleghanian event in the Blue Ridge. However, the possibility of continuous thermal diffusion in Paleozoic time has not yet been evaluated. In neither terrain is there as yet any radiogenic evidence of a proto-Taconic or Taconic event. It may be that tectonism and metamorphism at this time were negligible in these terrains or that there has been subsequent re-equilibration of Taconic minerals by later Acadian and Alleghanian thermal events.

The radiogenic data in the Reading Prong suggest a complexity beyond that observed from field studies (Buckwalter, 1962; Drake, 1969). Assuming that the Reading Prong dates are representative and meaningful (not established at this time, especially in view of the fact that all the Paleozoic dates are K/Ar whole rock), at least some of the Reading Prong thrusting or folding was late Paleozoic (e.g., Alleghanian; also see Drake, 1969). It seems unlikely that such age date differences

(287 and 372my vs. approximately 800my dates) resulted after emplacement of the thrust plates because the areas are in such close proximity.

The thermal 'hiatus' in the upper Precambrian and lowermost Paleozoic is not surprising and probably is more apparent than real. Most of the dates older than 600my are zircon determinations. A few are on microcline (Tilton and others, 1958). Thermal events easily could have occurred that were of insufficient intensity to yield a recrystallized zircon age. In some cases, Sr appears not to have been lost from microcline and an old age (1100my) has been retained (Tilton and others, 1958). On the other hand, burial could have been sufficiently deep to permit almost continuous loss of argon or strontium (item 64, Table 2) from micas, particularly if Blue Ridge volcanism were significantly more extensive than the present erosional remnants. Finally, Paleozoic regional metamorphism has almost certainly re-set K/Ar mica time clocks (with the exception of some biotites, Tilton and others, 1960) in the metasediments and pegmatites. Perhaps the only places where mica and feldspar ages older than 460my can be preserved are in inclusions of competent rock units within major plutons of Precambrian (or proto-Taconic) age (e.g., items 1, 2, 11, Table 2) and in less tectonically deformed units that have escaped recrystallization, but that were above the depth where elevated temperatures would permit continuous thermal diffusion (items 55 and 56, Table 2). Lithologic units at shallow depth or subjected to only slight metamorphic temperatures also may preserve old dates (see Harper, 1968).

In the Piedmont Province of Pennsylvania, at least two major episodes of regional metamorphism were followed by minor mineral reorientation, development of slip cleavage, and perhaps chloritization (Lapham, unpublished data; Freedman and others, 1964; Lapham and Bassett, 1964; Lapham and McKague, 1964). As an initial approximation, it probably is reasonable to assume that at least two of the regionally developed cleavages were formed under the same thermal-stress regime as the two major periods of regional metamorphism. The present view of some of the researchers in this area (Lapham, unpublished data; Higgins, written communication; Wetherill and others, 1966; Freedman and other, 1964; Lapham and Bassett, 1964) is that the peak of the most severe regional metamorphism was no younger than about 425my ago, both in Pennsylvania and in Maryland. Consequently, the D_1 deformation of Freedman and others (1964) also is believed to be no younger than 425my. However, it may be older if the D_2 upwarp in Pennsylvania is correlative with the last doming of the Maryland (and probably Pennsylvania) Precambrian gneisses which is believed to have occurred between 425 and 460my (note that this reasoning assumes that D_1 and D_2

belong to distinguishable tectonic events and that deformational fabrics and regional metamorphisms occurred penecontemporaneously).

The possibility that a 240 or 290my and/or a 320 to 350my thermal "event" may be the result of erosional unloading has been noted. Both may in part be attributed to stripping of the sedimentary cover. The recorded ages between 240my (or less) and 290my (or slightly more) are variable, sparse, and widely scattered. Such a pattern might be expected from differential erosion. On the other hand, the 320 to 350my thermal event is believed to include faulting, pegmatite intrusion, and, in the southern Appalachians, granitic pluton intrusion. Furthermore, from the dates determined on biotite and hornblende (lesser retentivity than muscovite) Wetherill and others (1966) have concluded that if unloading occurred at 310my it would have to have occurred rapidly. Nevertheless, the considerable erosional stripping of the Piedmont and the contribution of Piedmont rocks to Paleozoic sedimentary clastic wedges indicate that unloading at 320-350my is a viable explanation for many dates in this age group.

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GLOSSARY

Acadian. A period of tectonic activity in the late Devonian and early Carboniferous represented by age dates from 320 to 360my.

Alleghanian. Tectonic activity at the close of the Paleozoic represented by age dates between 220 and 300my.

D_1, D_2 *etc.* Deformations symbolized by subscript numbers, each subscript denoting a successive and separate deformational pattern or style.

Glenarm Series. A group of dominantly pelitic metamorphic rock units in the Piedmont of Pennsylvania of lower Paleozoic and/or Precambrian age.

Grenville (age or province). An age of Precambrian rocks that may represent a metamorphic recrystallization and that in Pennsylvania and Maryland has been correlated with rocks yielding age dates between 1050 and 1150my.

Fictitious Age. An apparent age; the analytically calculated age date of a rock and mineral that does not represent the true age of a geologic event.

Fission. The splitting of an atom yielding energy and two or more particles.

Inherited Age. An age date that is older than the rock (or mineral) dated and that results from admixed older and younger minerals, yielding an average, or fictitious age.

Isotope. Any one of two or more forms of the same chemical element, differing in atomic weight and often possessing radioactive properties.

Mixed Assemblage (of minerals). Used here to designate an assemblage of minerals of different ages.

my Abbreviation for million years.

Proto-Taconic. Tectonic events related to the Taconic orogeny (425-460my) but occurring previous to it in the Piedmont, probably between 460 and 600my, or Cambrian to early Ordovician.

Radiogenic. Of radioactive character or origin.

Radiometric. Referring to a radioactive isotopic measurement.

Re-equilibration. The re-establishment of equilibrium; used here for the equilibrium in a mineral between a radioactive element and its decay product(s).

Taconic. A period of tectonic activity in the Middle to Late Ordovician, represented by age dates between 425 and 460my.

Thermal Event. Any event or process (such as burial, metamorphism, faulting, etc.) which elevates the rock temperature above the surface temperature.

TABLE 2. *Summary of radiometric dates and related data for Pennsylvania and adjacent states*

	Formation	*Lithology*	*Location*	*Reported Apparent Age, my*	*Probable Actual Age(s), my*	*Isotope*	*Mineral or Whole Rock*	*References*	*Remarks*
					Piedmont Province				
1.	Baltimore Gneiss	Gneiss	Conshohocken, Pa.	1120	~1100	Pb^{207}/Pb^{206}	Z	Tilton and others, 1960	
				1050	~1100	Pb^{207}/U^{235}	Z	Tilton and others, 1960	
				1010	~1100	Pb^{206}/U^{238}	Z	Tilton and others, 1960	
				550		K/Ar	B	Tilton and others, 1960	
				380		Rb/Sr	B	Tilton and others, 1960	
2.	Baltimore Gneiss	Gneiss	Devault, Pa.	1010	~1050	K/Ar	B	Tilton and others, 1960	Possibly excess radiogenic argon (K/Ar age > Rb/Sr age).
				900	~1050	K/Ar	B	Tilton and others, 1960	
				630		Rb/Sr	B	Tilton and others, 1960	
				485		Rb/Sr	B	Tilton and others, 1960	
3.	Wissahickon Fm.	Schist	Somerton, Pa.	914		Pb-α	Z	Jaffe and others, 1959	Inherited zircon (?).
4.	Wissahickon Fm.	Schist	Fairmount, Pa.	880		Pb-α	Z	Jaffe and others, 1959; Stern and Rose (1961)	A corrected date.

Key:
Ar—Argon
B—Biotite
Chl—Chlorite
F—Feldspar
He—Helium
K—Potassium
Mi—Microcline
Mo—Monazite
Mt—Magnetite
Mu—Muscovite
O—Orthoclase
P—Phlogopite
Pb—Lead
Pg—Plagioclase
Px—Pyroxene
Py—Pyrite
Ra—Radium
Rb—Rubidium
Sr—Strontium
Th—Thorium
U—Uranium
W. R.—Whole Rock
Z—Zircon

Figure 1 Map of radiometrically dated samples by geologic province

TABLE 2. *Summary of radiometric dates and related data for Pennsylvania and adjacent states*

	Reported Apparent	*Probable Actual*	*Mineral or Whole*

5.	Wissahickon Fm.	Schist	W. Manayunk, Pa.	840		Pb-α	Z	Jaffe and others, 1959; Stern and Rose (1961)	A corrected date.
6.	Wissahickon Fm.	Schist	Clifton Heights, Pa.	785		Pb-α	Z	Jaffe and others, 1959	Uncorrected date.
7.	Wissahickon Fm.	Schist	W. Manayunk, Pa.	529	>530	Pb-α	Mo	Jaffe and others, 1959	Uncorrected date.
8.	Wissahickon Fm.	Muscovite schist	Swarthmore, Pa.	529	>530	Pb-α	Mo	Jaffe and others, 1959	Uncorrected date.
9.	Swarthmore Pluton	Granodiorite	East Lake Park, Pa.	480		Pb-α	Z	Jaffe and others, 1959; Stern and Rose (1961)	A corrected date.
10.	Swarthmore Pluton	Granodiorite	Clifton Heights, Pa.	460		Pb-α	Z	Jaffe and others, 1959; Stern and Rose (1961)	A corrected date.
11.	Metagabbro (?)	Plagioclase-hornblendite	Pleasant Grove, Pa.	460 ± 20	460-480 or older	K/Ar	B	Lapham and Bassett, 1964	Post ultramafic and Wissahickon Schist.
12.	Baltimore Gneiss	Gneiss	Radnor, Pa.	396 ± 14		K/Ar	B	Long and others, 1959	May belong to 420-480my age group rather than 320-350 group.
13.	Pegmatite	Granitic pegmatite	Pleasant Grove, Pa.	395 ± 20	~450 and 330 (?)	K/Ar	Mu	Lapham and Bassett, 1964	A partially requilibrated mica.
14.	Wissahickon-east(?)	"Granitized" schist	Pleasant Grove, Pa.	360 ± 18	~450 and 330 (?)	K/Ar	Mu	Lapham and Bassett, 1964	A mixed-mica date.
15.	Wissahickon Fm.	Metasubgraywacke	Safe Harbor, Pa.	360 ± 18	?~450	K/Ar	B, Mu	Lapham and Bassett, 1964	A mixed-mica date; biotite is older.
16.	Wissahickon-east(?)	"Granitized" schist	Pleasant Grove, Pa.	355 ± 18	~450 and 330 (?)	K/Ar	B, Mu	Lapham and Bassett, 1964	A mixed-mica date; biotite is older.

TABLE 2. *Summary of radiometric dates and related data for Pennsylvania and adjacent states (Continued)*

	Formation	*Lithology*	*Location*	*Reported Apparent Age, my*	*Probable Actual Age(s), my*	*Isotope*	*Mineral or Whole Rock*	*References*	*Remarks*
17.	Wissahickon Fm.	Schist	Neshaminy Falls, Pa.	353 ± 14		K/Ar	Mu	Long and Kulp, 1962	
18.	Peters Creek Fm.	Metasubgray-wacke	Fishing Creek at Susquehanna River, Pa.	330 ± 15		K/Ar	W. R.	Lapham and Bassett, 1964	
19.	Pegmatite	Or-Mu-Chl pegmatite	1 mile east of Pilot, Md. near Pa. State Line	330 ± 15		K/Ar	Mu	Lapham and Bassett, 1964	Intrusive into ultra-mafic rock.
20.	Peters Creek Fm.	Schist	Fishing Creek at Susquehanna River, Pa.	325 ± 15		K/Ar	W. R.	Lapham and Bassett, 1964	
21.	Peach Bottom Fm.	Slate	Peach Bottom Quarry, Pa.	320 ± 15		K/Ar	W. R.	Lapham and Bassett, 1964	
22.	Peters Creek Fm.	Mica-quartz schist	2 miles south of Fishing Creek on Susquehanna River, Pa.	305 ± 15	330	K/Ar	W. R.	Lapham and Bassett, 1964	Probably some radio-genic argon loss.
23.	Swarthmore Pluton	Granodiorite	Springfield, Pa.	293	330-350	Pb-α	Z	Jaffe and others, 1959	Uncorrected date.
24.	Pegmatite	Or-mica pegmatite	2.5 miles south of Safe Harbor	285 ± 15	330	K/Ar	Or	Lapham and Bassett, 1964	In Wissahickon Schist; radiogenic argon loss.

25.	Swarthmore Pluton	Granodiorite	Springfield, Pa.	241 218		Pb-α Pb-α	Z Z	Jaffe and others, 1959	Uncorrected dates.
26.	Swarthmore Pluton	Granodiorite	Fairmount, Pa.	216		Pb-α	Z	Jaffe and others, 1959	Probably 280-290 or 320-350my.
				Blue Ridge Province					
27.	Catoctin Fm.	Metarhyolite	South Mountain, Pa.	700 558 524	820 820 820	Pb^{207}/Pb^{206} Pb^{207}/U^{235} Pb^{206}/U^{238}	Z Z Z	Rankin and others, 1969	Episodic Pb loss at 240my.
28.	Catoctin Fm.	Metarhyolite	South Mountain, Pa.	484	850 (?)	Pb-α	Z	Jaffe and others, 1959	Uncorrected date.
29.	Catoctin Fm.	Metarhyolite	Lat. 40°03′13″ Long. 77°12′03″ South Mountain, Pa.	324 ± 10		Rb/Sr	W. R.	Unpublished data, Pa. Geol. Survey	Not evaluated; $\lambda = 1.47 \times 10^{-4}$ yr.$^{-1}$ and $(Sr^{87}/Sr^{86})_0 = 0.705$
30.	Catoctin Fm.	Metarhyolite	Lat. 39°57′16″ Long. 77°20′08″ South Mountain, Pa.	306 ± 4		K/Ar	W. R.	Unpublished data, Pa. Geol. Survey	Not evaluated.
31.	Catoctin Fm.	Metarhyolite	Lat. 39°57′23″ Long. 77°20′20″ South Mountain, Pa.	269 ± 3		K/Ar	W. R.	Unpublished data, Pa. Geol. Survey	Not evaluated.
32.	Catoctin Fm.	Metarhyolite	Lat. 39°53′50″ Long. 77°25′03″ Same locality as item 27	261 ± 10		Rb/Sr	W. R.	Unpublished data, Pa. Geol. Survey	Not evaluated; $\lambda = 1.47 \times 10^{-4}$ yr.$^{-1}$ and $(Sr^{87}/Sr^{86})_0 = 0.705$

TABLE 2. *Summary of radiometric dates and related data for Pennsylvania and adjacent states (Continued)*

	Formation	*Lithology*	*Location*	*Reported Apparent Age, my*	*Probable Actual Age(s), my*	*Isotope*	*Mineral or Whole Rock*	*References*	*Remarks*
				Reading Prong Province					
33.	Serpentinized marble	Pegmatite associated with hydrothermal mineralization	Easton, Pa.	890		Pb-α	Z	Jaffe and others, 1959	Uncorrected date.
34.	Highland Gneiss	Gneiss	Wernersville, Pa.	821 ± 25	1150, 830-840	K/Ar	B	Long and Kulp, 1962	Event at 830-840my is probably a recrystallization.
35.		Pegmatitic granite gneiss	Lat. 40°17′55″ Long. 76°10′57″ Robesonia, Pa.	804 ± 9		K/Ar	Mu	Unpublished data, Pa. Geol. Survey	Not evaluated.
36.		Biotite-graphite gneiss	Lat. 40°18′02″ Long. 76°08′10″ Robesonia, Pa.	742 ± 7		K/Ar	B	Unpublished data, Pa. Geol. Survey	Not evaluated.
37.		Hornblende granite gneiss	Lat. 40°23′14″ Long. 75°48′58″ Reading, Pa.	372 ± 4		K/Ar	W. R.	Unpublished data, Pa. Geol. Survey	Not evaluated.
38.		Granite gneiss	Lat. 40°21′21″ Long. 75°52′11″ Reading, Pa.	287 ± 8		K/Ar	W. R.	Unpublished data, Pa. Geol. Survey	Not evaluated.

*Valley and Ridge Province**

39.	Martinsburg Fm.	Shale	Lat. 39°47′20″ Long. 77°42′23″ Greencastle, Pa.	473 ± 5		K/Ar	W. R.	Unpublished data, Pa. Geol. Survey	Not evaluated.
40.	Reedsville Fm.	Shale	McConnellsburg, Pa.	430	444 ± 9	K/Ar	W. R.	Pierce and Armstrong, 1966; Armstrong, 1970	Original date revised by isotope dilution method (Armstrong, 1970).
41.	Hamilton Group	Shale	Three samples: Stroudsburg, Pa., Amity Hall, Pa., Georges Twp., Fayette Co., Pa.	398 ± 12		Rb/Sr	W. R.	Whitney and Hurley, 1964	Samples are Middle Devonian Hamilton shales within 15% of actual Devonian age; possibly derived from a young source.
				384 ± 9		Rb/Sr	W. R.	Bofinger and Compston, 1967	Recalculated values of above samples may be as low as 377my.
42.	"Bunker Hill Intrusives"	Diabasic unit	Bunker Hill, Pa.	375 ± 15		(Ra, Th)-He	W. R.	Urry, 1936	Probable helium loss; intrusives in the Martinsburg Formation.
43.	Reedsville Fm.	Shale mylonite	McConnellsburg, Pa.	360 320	372 ± 8	K/Ar K/Ar	W. R. W. R.	Pierce and Armstrong, 1966; Armstrong, 1970	Argon loss due to faulting; original date revised by isotopic dilution method (Armstrong, 1970)
44.	"Bunker Hill Intrusives"	Diabasic unit	Bunker Hill, Pa.	355 ± 15		(Ra, Th)-He	W. R.	Urry, 1936	Probable helium loss; intrusives in the Martinsburg Formation.

TABLE 2. *Summary of radiometric dates and related data for Pennsylvania and adjacent states (Continued)*

	Formation	*Lithology*	*Location*	*Reported Apparent Age, my*	*Probable Actual Age(s), my*	*Isotope*	*Mineral or Whole Rock*	*References*	*Remarks*
45.	Martinsburg Fm.	Shale mylonite	Lat. 39°47′20″ Long. 77°42′30″ Greencastle, Pa.	324 ± 3		K/Ar	W. R.	Unpublished data, Pa. Geol. Survey	Not evaluated.
46.	"Bunker Hill Extrusives"	Basalt flow	Bunker Hill, Pa.	145 ± 8		(Ra, Th)-He	W. R.	Urry, 1936	Probable helium loss; volcanics in the Martinsburg Formation.
47.	"Bunker Hill Extrusives"	Basalt flow	Bunker Hill, Pa.	140 ± 7		(Ra, Th)-He	W. R.	Urry, 1936	Probable helium loss; volcanics in the Martinsburg Formation.

*Note added in press: An age date for total U and Pb in unpurified coffinite grains is given as 335 ± 20my by R. Smith in "Electron Microprobe Study of Some Minerals from the Mt. Pisgah Uranium Occurrence, Carbon County, Pa.", 1969, report on file, Lafayette College, Easton, Pa. Analysis showed 51.6% UO_2, 41.7% SiO_2, 2.22% PbO, and traces of Al_2O_3, CaO, Fe_2O_3, and volatiles. The coffinite occurs in the Mauch Chunk Formation of Mississippian age in the eastern portion of the Valley and Ridge Province of Pennsylvania.

*Triassic Lowlands Province**

48.	Magnetite ore sample	Limestone replacement	Boyertown, Pa.	240	190-195	(U, Th)-He	Mt	Green and Damon, 1963	Magnetite was leached
49.	Magnetite ore sample	Limestone replacement	Dillsburg, Pa.	203		(U, Th)-He	Mt	Green and Damon, 1963	Magnetite was leached 15%

50. Magnetite ore sample	Limestone replacement	Cornwall, Pa.	202 190 188		(U, Th)-He (U, Th)-He (U, Th)-He	Mt Mt Mt	Green and Damon, 1963	Magnetite was leached 10%
51. Magnetite and pyrite ore samples	Limestone replacement	Cornwall, Pa.	197 ± 6 196 ± 6 188 ± 6 174 ± 15	196 196 196 196	(U, Th)-He	Mt Mt Mt Py	Fanale and Kulp, 1962	
52. Metasomatic aureole	Chloritic "schist"	Cornwall, Pa.	195 ± 5		K/Ar	Mu	Fanale and Kulp, 1962	
53. Diabase (Triassic)	Diabase	Pa. No precise location given	170	195	(U, Th)-He	Mt	Hurley, in Erickson and Kulp, 1961	
54. Magnetite ore sample	Limestone replacement	French Creek, Pa.	160	195	(U, Th)-He	Mt	Fanale and Kulp, 1962	

* Note added in press: K/Ar W. R. dates on diabase from southeast of Pottstown, Montgomery Co.: 223 ± 13 and 227 ± 10 (Armstrong and Besancon, 1970).

Appalachian Plateaus Province

55. "Basement" below Cambrian sediments at 5962′	Biotite phyllite	Lat. 42°08′33″ Long. 80°02′50″ Hammermill No. 2 Well, Erie, Pa.	908 ± 9	K/Ar	W. R.	Unpublished data, Pa. Geol. Survey	Not evaluated; see description by Saylor, 1968; $\lambda = 1.47 \times 10^{-11}$ yr^{-1} and $(Sr^{87}/Sr^{86})_0 = 0.705$
			544 ± 15	Rb/Sr	W. R.		
56. "Basement" below Cambrian sediments at 5962′	Quartz-muscovite schistose granite	as item 55	633 ± 19	Rb/Sr	W. R.	Unpublished data, Pa. Geol. Survey	Not evaluated; see description by Saylor, 1968; $\lambda = 1.47 \times 10^{-11}$ yr^{-1} and $(Sr^{87}/Sr^{86})_0 = 0.705$

TABLE 2. *Summary of radiometric dates and related data for Pennsylvania and adjacent states (Continued)*

	Formation	Lithology	Location	Reported Apparent Age, my	Probable Actual Age(s), my	Isotope	Mineral or Whole Rock	References	Remarks
57.	Dike cutting Upper Pennsylvanian sediments	Peridotite	Adah, Pa.	408 ± 20 368 ± 18		K/Ar	P	Zartman and others, 1967	Excess radiogenic argon.
			Maryland Piedmont: Selected Dates						
58.	Baltimore gneiss (Phoenix Dome)	Gneiss	Md. Piedmont	1190 ± 100 1130 ± 100 1120 ± 25	~1100 ~1100 ~1100	Rb/Sr Rb/Sr Pb^{207}/Pb^{206}	Mi Mi Z	Tilton and others, 1958	
59.	Baltimore Gabbro	Gabbro	Md. Piedmont	702 580	<700	K/Ar K/Ar	Px Pg	Wetherill and others, 1966	
60.	Norbeck Pluton	Qtz. diorite	Md. Piedmont	565 ± 20		Pb^{207}/Pb^{206}	Z	Wetherill and others, 1966	Possibly 600my ± 60.
61.	Kensington Pluton	Qtz. diorite	Md. Piedmont	540 ± 20 510 ± 20 385 350		Pb^{207}/Pb^{206} Pb^{207}/Pb^{206} K/Ar K/Ar	Z Z B B	Wetherill and others, 1966	Possibly 600my ± 60.
62.	Relay, Gunpowder and Port Deposit Plutons	Qtz. diorite, "granite", and qtz. diorite respectively	Md. Piedmont		(?) 550 ± 50	Pb^{207}/Pb^{206}	Z	Wetherill and others, 1966; Steiger and Hopson, 1964	Estimated age; under revision by Higgins (pers. communication).
63.	Ellicott City Pluton	Granodiorite	Md. Piedmont	450 ± 20 315		Pb^{207}/Pb^{206} K/Ar	Z B	Wetherill and others, 1966	Possibly 600my ± 60; core may be younger.

64.	Woodstock pluton	Qtz. monzonite	Md. Piedmont	410 ± 20 305 295		Pb^{207}/Pb^{206} Rb/Sr K/Ar	Z B B	Wetherill and others, 1966 and Tilton and others, 1958	Possibly younger than Pegmatite swarms.
65.	Pegmatite swarms		Md. Piedmont	280-395	425 ± 20	Rb/Sr, K/Ar	Mu, B, F	Wetherill and others, 1966	Post major regional metamorphism; associated with doming.
66.	Pegmaties (small)		Md. Piedmont	~345		Rb/Sr	Mu, F	Wetherill and others, 1966	May be re-equilibrated.
67.	Port Deposit	"Granodiorite"	1.5 miles north of Port Deposit, Md.	330 ± 15		K/Ar	B	Lapham and Bassett, 1964	A re-equilibration age.
				West Virginia and Ohio: Selected Dates					
68.	Basement Gneiss	Granite gneiss	W. Va.	870		Rb/Sr	B	Tilton and others, 1960	
69.	Basement Gneiss	Tonalite to amphibolite	Ohio	920-950		Rb/Sr	B, Mu	Tilton and others, 1960	
				New Jersey: Selected Dates					
70.	Franklin Marble	Marble	Ogdensburg	903 ± 25		K/Ar	P	Long and Kulp, 1962	Reading Prong.
71.	Losee	Gneiss	Sparta	845 ± 25	835	Rb/Sr	B	Long and Kulp, 1962	Reading Prong.
72.		Granodiorite gneiss	Sparta	839 ± 42	835	K/Ar	B	Long and Kulp, 1962	Reading Prong.
73.		Biotite gneiss	McAfee	822 ± 33	835	K/Ar	B	Long and Kulp, 1962	Reading Prong.
74.	Franklin Marble	Pegmatite	Franklin	811 ± 32	~835	K/Ar	B	Long and Kulp, 1962	Reading Prong.

TABLE 2. *Summary of radiometric dates and related data for Pennsylvania and adjacent states (Continued)*

	Formation	*Lithology*	*Location*	*Reported Apparent Age, my*	*Probable Actual Age(s), my*	*Isotope*	*Rock or Whole Rock*	*References*	*Remarks*
75.	"Basement" Gneiss	Feldspar-quartz-mica gneiss	Island Beach State Park	235		K/Ar	B	Southwick, 1964	A drill core sample; Paleozoic, or older, basement.
76.	Palisades Sill	Diabase	N. J.	190 ± 5		K/Ar	B	Erickson and Kulp, 1961	
77.	Watchung Flow	Basalt	N. J.	79	>79	K/Ar	W. R.	Erickson and Kulp, 1961	Assumes flow and sill are same age; i.e., 195my.
				New York: Selected Dates					
78.	Canada Hill	Gneiss	Bear Mtn.	869 ± 35	~840	K/Ar	B	Long and Kulp, 1962	Reading Prong Highlands.
79.	Storm King	Granite	Bear Mtn.	851 ± 34	~840	K/Ar	B	Long and Kulp, 1962	Reading Prong Highlands.
80.	Canada Hill	Gneiss	Bear Mtn.	819 ± 25	~840	Rb/Sr	B	Long and Kulp, 1962	Reading Prong Highlands.
81.	Highland Gneiss	Pegmatite	Lake Tiorati	765 ± 24		K/Ar	B	Long and Kulp, 1962	Reading Prong Highlands; chloritized.
82.	Yonkers Gneiss	Granite gneiss	Yonkers	575 ± 30		Rb/Sr	W. R.	Long, 1969	Manhattan Prong.

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